Oil-Free Compression for Hydrogen Delivery and Transportation – Foil Bearings

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Mohawk Innovative Technology, Inc.

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Project ID # PDP10

DOE Hydrogen Program

Overview

Timeline

- June 27, 2006
- June 27, 2008
- 85 Percent Complete

Budget*

- Total proposed project funding
  - $750,000 DOE SBIR
  - $0
- $350,000 FY07 Funding
- $350,000 FY08 Funding

Barriers

- Hydrogen Delivery Compressor
  - Reliability
  - System Cost
  - Efficiency of H2 Gas Compression

Partners

- Lead: Mohawk Innovative Technology, Inc. (MiTi®)
- Mitsubishi Heavy Industries

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Objectives

- Assess feasibility of centrifugal compressors for hydrogen transmission and delivery
  - Demonstrate full-scale oil-free foil bearings in compressor simulator rig hardware
  - Test candidate bearing/shaft materials and coatings

Reference Design Requirements

500,000 kg/day Mass Flow
Pressure Rise From 500 up to 1200 Psig
100-200 Mile Transmission Distance

Project Milestones

Month/Year	Milestone or Go/No-Go Decision
Sept-06	**Project Milestone:** Update preliminary modular centrifugal compressor design to achieve pressure and flow.
Jan-07	**Project Milestone:** Complete Bearing & Test Rig Designs
Mar-07	**Project Milestone:** Complete Tribological Testing
Jul-07	**Project Milestone:** Fabricate Foil Bearings and Rig Mods
Apr-08	**Project Milestone:** Complete Simulator Testing

Oct-09	**DOE Milestone:** Down select novel compression technology for hydrogen delivery.

Project Plan

- Demonstrate Feasibility of Oil-Free Hydrogen Centrifugal Compressor
  - Refine Compressor System Concept
  - Design Rotor-Bearing Dynamic Simulator
    - Full Size Rotor and Bearings
    - Simulate Dynamics and Bearing Loads
  - Validate Bearing Capability And Shafting Design Through Dynamic Testing In Air
    - Rotor-Bearing Operation Above Bending Critical Speed
    - Operation with Side Loads
    - Identify Impact of Hydrogen
  - Identify Candidate Bearing and Shafting Coatings with Appropriate Friction and Wear Life

Progress

- System Configuration Assessment Complete
- All Design and Fabrication Tasks Complete
- Bearing and Shaft Coating Tests Complete
- Rotor-Bearing Simulator Testing In Progress
  - Operation Above Bending Critical Speed on Gas Foil Bearings Demonstrated
  - Impact of Hydrogen Embrittlement Demonstrated

Compressor Design

Final Summary							
Maximum Head = 60,000 ft			Maximum Discharge Temp = 300F			Interstage Temperature = 200F	
Compressor Stage	Power (hp)	Pressure (psig)	Suction Flow (Cu-ft/min)	Speed (rpm)	Specific Diameter	Diameter (Inches)	Tip Speed (ft/sec)
Inlet		**500**	**3616**				
1	1626	573	3616		1.50	6.45	1521
2	1718	645	3400		1.56	6.42	1513
3	1814	727	3194		1.63	6.41	1511
Outlet #1	**5158**	**727**		**54000**			
Inlet #2		**712**					
4	1918	817	2960		1.55	5.92	1550
5	2028	922	2776		1.62	5.91	1548
Outlet #2	**3946**	**922**		**60000**			
Inlet #3		**912**					
6	2262	1054	2570		1.54	5.48	1578
7	2400	1200	2400		1.62	5.48	1578
Outlet #3	**4662**			**66000**			

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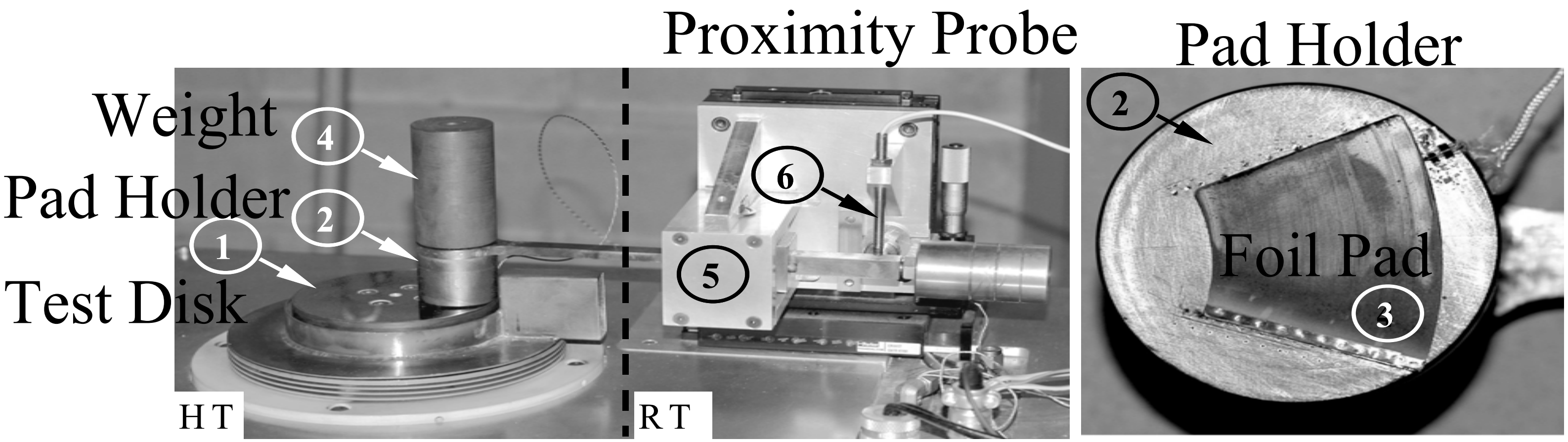
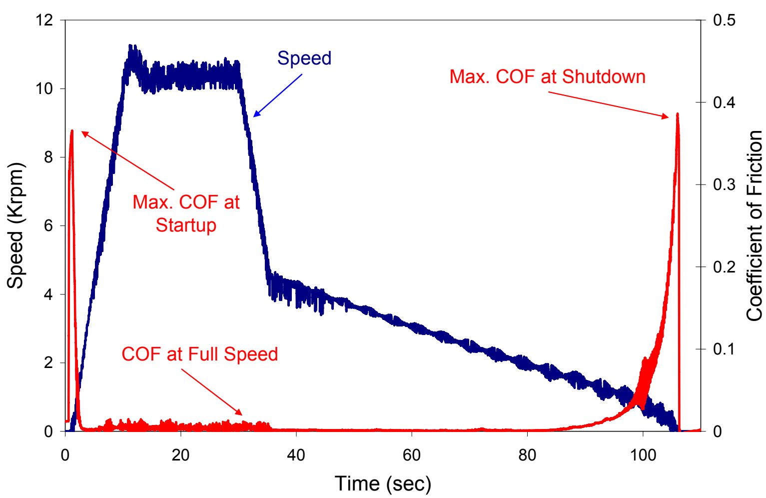
Foil Bearing Coating Testing





Coatings		Temperature	COF		Liftoff
Pad	Disc	(Deg-C)	Max	Full Speed	Speed
K900	High Dense Chrome	RT	0.35	0.003	500
		300	0.32	0.002	250
		500	0.25	0.005	900
K900	DLC	RT	0.33	0.002	500
		300	0.23	0.008	250
K900	H-DLC	RT	0.32	0.003	600
		300	Did Not Lift Off		
H-DLC	K900	RT	Erratic Behavior and Early Failure		

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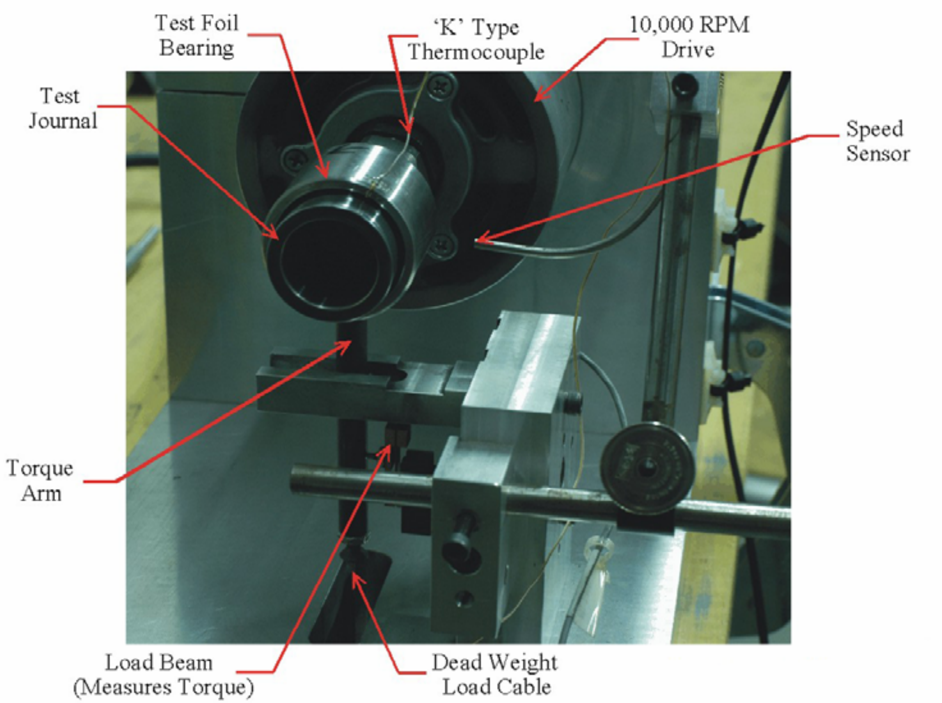
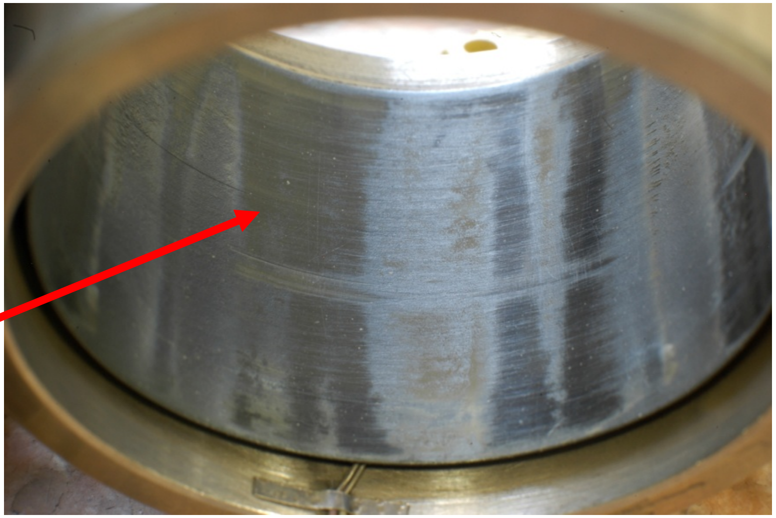
Foil Bearing Coating Testing



- Start Stop Cyclic Testing
  - 100,000 Cycles
  - Korolon® 800 versus High Dense Chrome



Burnishing of Coating

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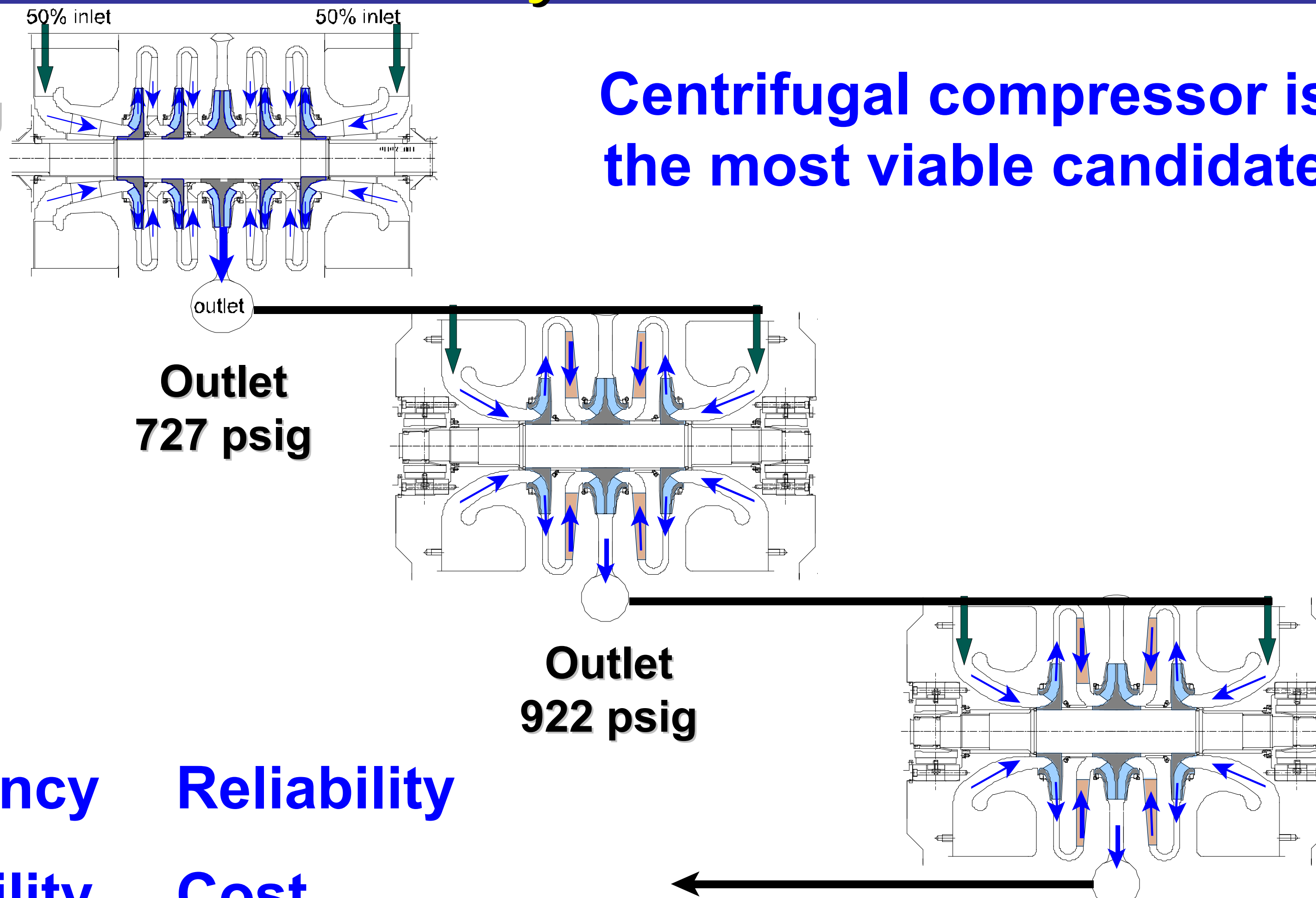
Modular Double Entry Compressor System



Centrifugal compressor is the most viable candidate

Efficiency **Reliability**

Durability **Cost**

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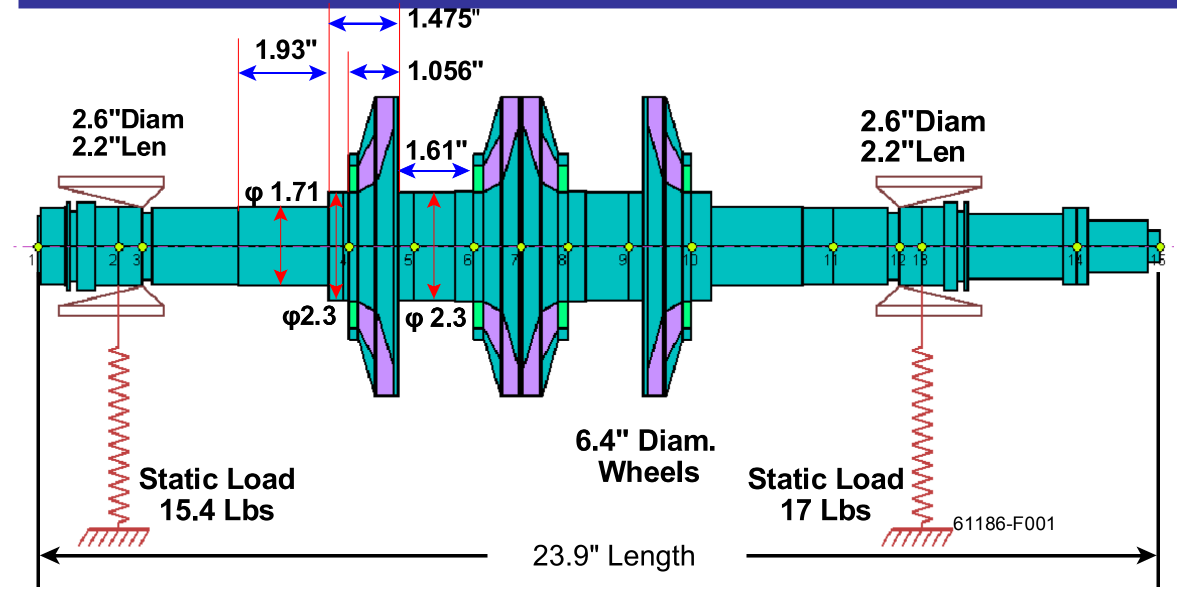
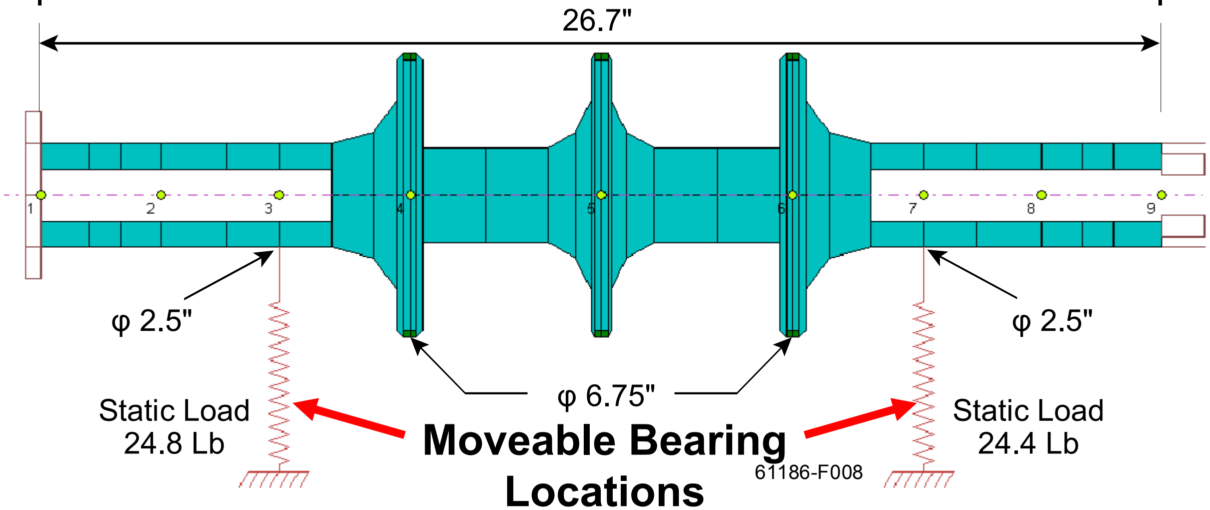
Rotor-Bearing Simulator FE Model



60,000 rpm Compressor Concept Design



60,000 rpm Simulator Rotor-Bearing Design

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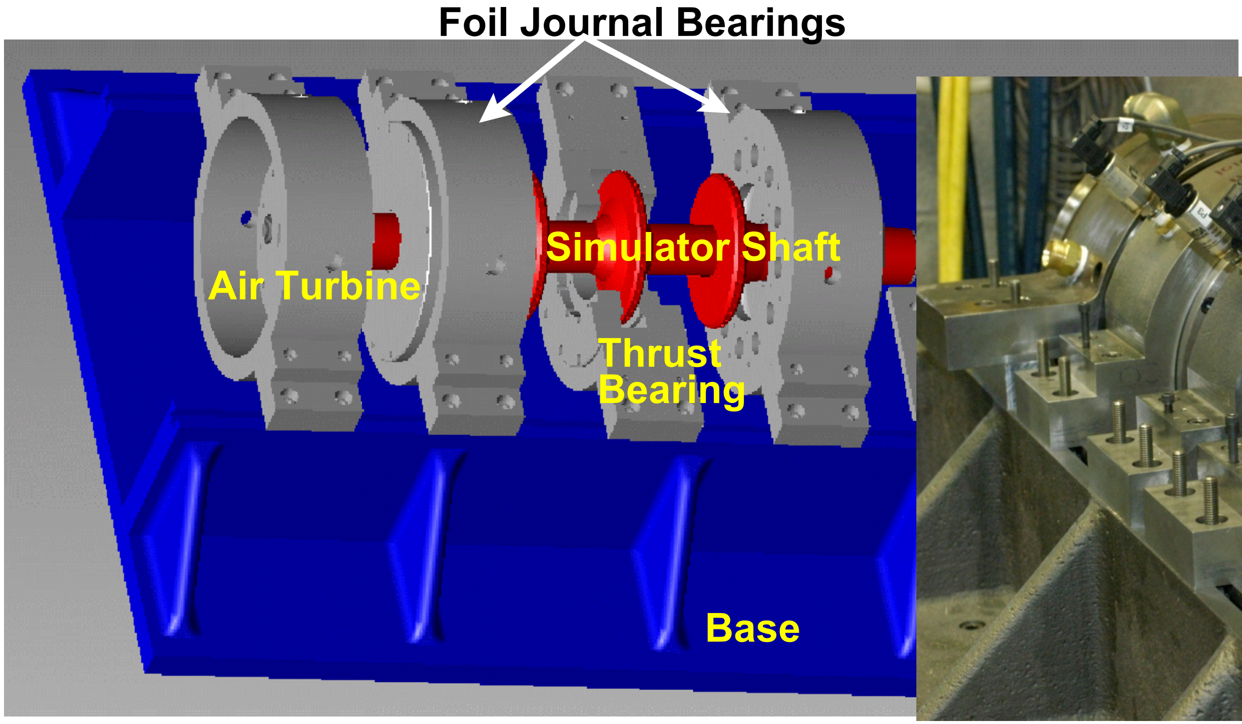
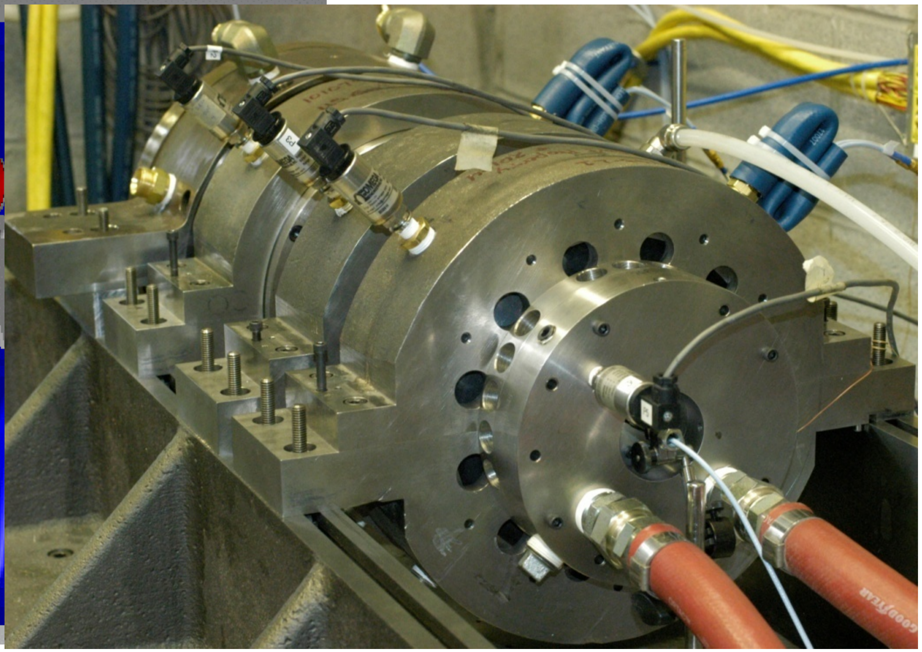
Simulator Test Rig





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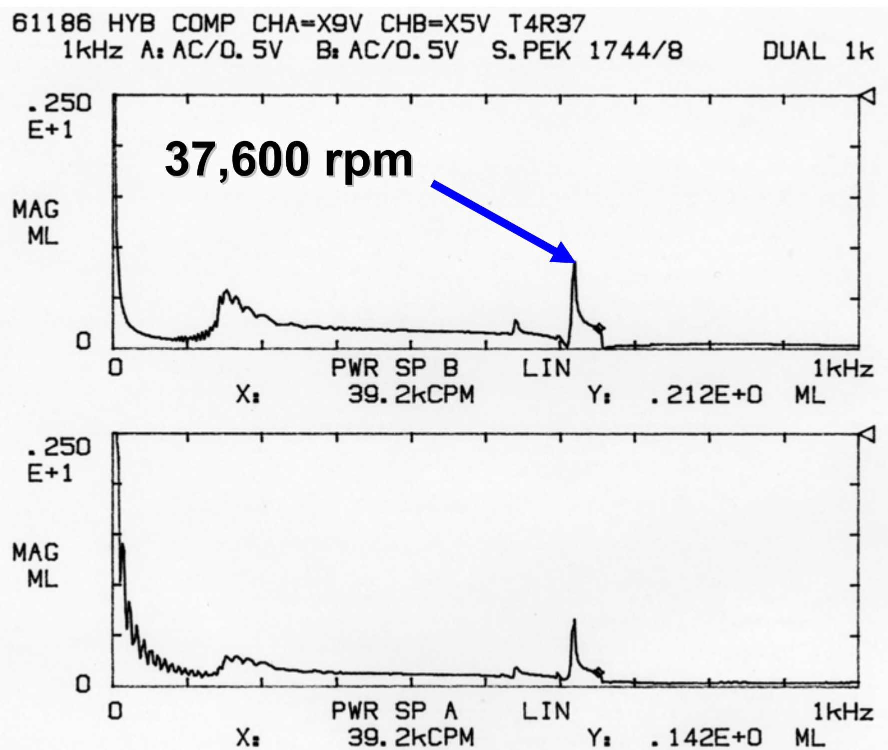
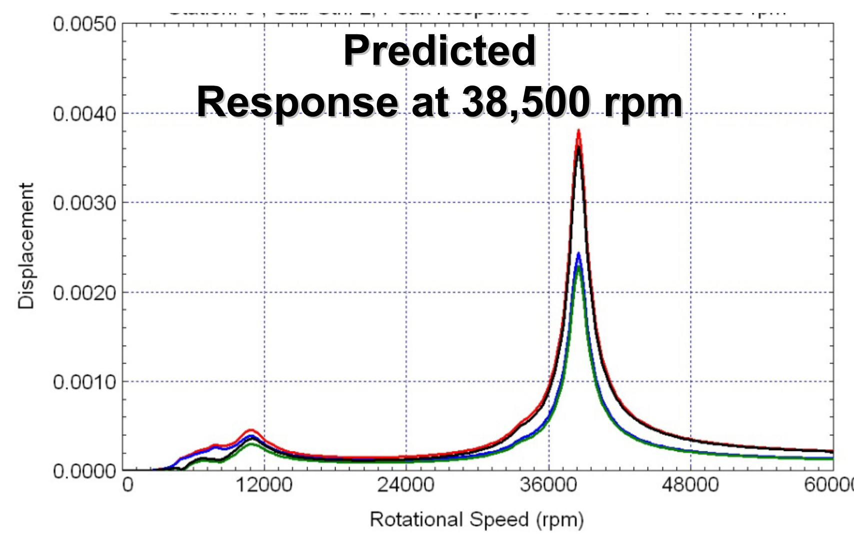
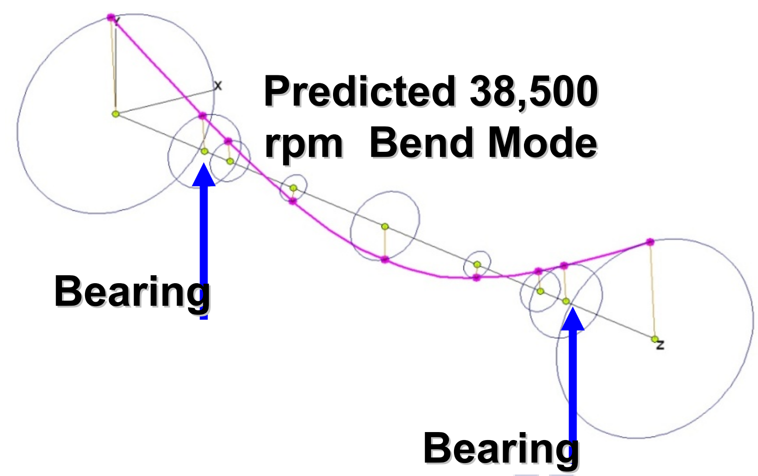
Operation Above Bending Mode

Measured Response







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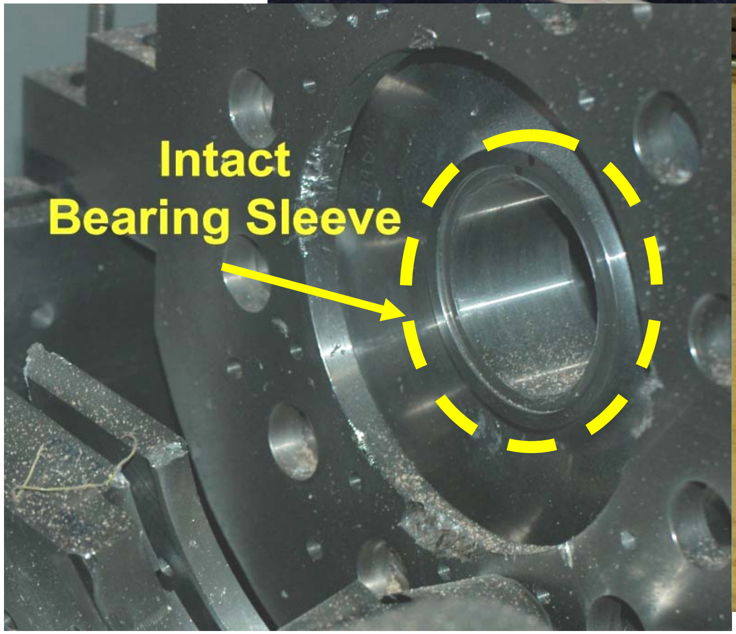
Simulated H2 Embrittlement



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Identified Technology Needs

- **High Speeds in Hydrogen Dictate**
  - Advanced Centrifugal Compressor
  - High-Speed, Oil-Free Foil Bearings
  - Low Friction and Long Wear Life Hydrogen Compatible Coatings
  - Hydrogen Compatible High Strength Shaft Materials

Future Work for FY08

- **Complete Dynamic Testing Under Different Bearing Loading Conditions**
  - Rotating Imbalance Loads
  - Steady Side Loads
- **Refine System Concept & Component Designs**
  - Number of Compression Stages
  - Operating Speeds
  - Foil Bearing Designs Based Experimental Data
    - Steady and Dynamic Loads
    - Required Damping
  - Identify Technology Readiness and Development Needs

Project Summary

- **Hydrogen Centrifugal Compressor Operating at Very High-speeds Require Oil-free Compliant Foil Bearings**
- **Multi-stage, High-speed Centrifugal Compressors Operating in Series Are Necessary and Feasible As Demonstrated By:**
  - **Low Friction and Long Wear Life of Korolon**
  - **Operation Above Bending Critical Speeds on Foil Bearing**
- **Additional Technology Needs**
  - **High Efficiency Dynamic Seals**
  - **Testing at High Pressures and Flow Rates Through Foil Bearings**
  - **Structural, Bearing and Coating Material Compatibility With Hydrogen**

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